

# NAVFAC EXWC Demonstrates New Renewable Energy Power Management Systems

## Power Converters Key to Further Reductions in Photovoltaic System Costs

**IN AN EFFORT** to drive down the cost of using photovoltaic (PV) -generated electricity, engineers from the Naval Facilities Engineering Command (NAVFAC) Engineering and Expeditionary Warfare Center (EXWC) are working on a new kind of power converter.

The project, sponsored by the Office of Naval Research's (ONR) Energy Systems Technology Evaluation Program (ESTEP), is taking an alternative approach to reducing PV system cost. Instead of focusing on the cost of the PV modules and hardware, ESTEP began to look into ways they could leverage recent advancements in power electronics. And in 2012, the program tasked EXWC with exploring ways to reduce the cost of PV inverters, a key part of any PV system.

goal of this project was to acquire a universal power converter that could be applicable to numerous applications. This would increase demand, simplify installation, and provide economies of scale.

Generally speaking, the most common way to manage power conversion in a renewable micro-grid is to bundle multiple inverters and rectifiers (which convert AC to DC) together and use a controller to switch the power flow as needed. However, such a design is expensive and inefficient in terms of conversion losses at each stage, as well as being physically large and heavy. There is a current paradigm shift in how to implement hybrid systems consisting of PV and batteries by making the power converter the central point of connection.

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### Inverters & Converters

PV panels produce direct current (DC), but the power grid works on alternating current (AC). Therefore, any PV system requires a mechanism to transform one form of energy into another. In PV systems, this mechanism is almost always an inverter, which performs DC to AC inversion only.

Power converters can convert DC to AC or AC to DC, and have several other advantages over inverters alone. The

Traditionally, power conversion has been achieved using large metal core transformers which step up or down the voltage. Metal core transformers are very efficient and reliable, but they are analogous to an analog system as the world increasingly becomes digital. There are still many legacy PV inverters in service that are built around this technology.

Solid state power converters employ electronic switching circuitry that switches at high frequency which reduces the size of the transformer needed. In essence, solid

state power converters are digital instruments that separate AC signals into DC pulses which are reassembled to the correct AC/DC voltage and current. Solid state power converters are thus more intelligent and flexible in how they convert power. However, because solid state power converters use more electronic circuitry, there are more electronic components which are more sensitive to environmental degradation and failure.

Magnetic components, including transformers, reactors, and inductors are the largest, heaviest and the most expensive components in an inverter. Solid state PV inverters use smaller transistor elements that have achieved a significant cost reduction in PV

inverters by reducing the amount of magnetic metal and copper used.

## Innovations in Power Electronics

New developments in power electronics such as lower cost micro-processors, longer-life capacitors (which store the electric charge), and more powerful transistors have advanced the development of solid state power converters and enabled them to be more compact, robust and have multi-functionality. This multi-functionality of a single hardware platform is offered by a few startup companies that have introduced new innovative power electronics topologies. One such company is Ideal Power Converters (IPC) which developed a new power converter tech-

nology that encompassed many of these advancements.

Conventional power electronic topologies employ a continuous one-way power flow for direct power conversion. The IPC system uses a patented Power Packet Switching Architecture which collects and stores the energy in packets using an AC link and then redistributes them. Conventional power conversion is continuous much like a continuous stream of water. (Note: More about IPC's topology and the advantages it offers can be found at [www.IdealPowerConverters.com](http://www.IdealPowerConverters.com).)

Another advance in the power electronics field is in the area of control electronics. Control electronics in general is defined as software or hard-

## The Basics About ESTEP

**ESTEP FOCUSES ON** energy technologies that reduce costs, increase energy security, and ultimately increase the reach and persistence of the warfighter. The entire program encompasses the following investment areas:

- Cyber and Energy Management for Information Systems
- Power and Energy Components
- Power and Energy Production/Efficiency

ESTEP, established in fiscal year 2013, is casting a wide net across the Department of the Navy, academia, and private industry to investigate and test emerging energy technologies at Navy and Marine Corps installations. At present, ESTEP conducts over 20 in-house government energy projects, ranging from energy management to alternative energy and storage technologies. Additionally, an ESTEP Broad Agency Announcement has awarded several contracts to industry in those same energy areas.

In addition to testing and evaluating the performance and reliability of energy technologies, the ESTEP program provides mentoring (via on-the-job training and education of interns) and other workforce development opportunities by partnering with the Troops-to-Engineers program for veterans at San Diego State University and other universities.

For more information on the ESTEP program, visit [www.aptep.net/partners/estep](http://www.aptep.net/partners/estep). For additional details about EXWC-executed ESTEP projects, visit [www.aptep.net/projects/technology/estep-projects/exwc-projects](http://www.aptep.net/projects/technology/estep-projects/exwc-projects).





The new PV inverter installed at EXWC replaced six older solid state single-phase PV inverters (shown on the right), taking up approximately 30 percent of the footprint of the old system.

*Ken Ho*

ware that enables complex control of the semiconductor switches and allows for more novel topologies. Improvements in performance and cost of microprocessor controllers, combined with recent developments in digital controls is offering tremendous possibilities from which to create new features, improve performance and offer greater product flexibility. Using software control, the power converter operating characteristics can now be dictated by a stored program rather than a set of discrete components. What this means is that a modern power converter, if designed correctly, can have its function upgraded or changed using software. This makes development of a universal power converter hardware, flexible enough for multiple functions, now feasible.

### Photovoltaic Application

To demonstrate the feasibility of one of these systems, a 30 kilowatt (kW) IPC PV inverter was installed in 2015 at Naval Base Ventura County (NBVC) in Port Hueneme, California. This PV

inverter had a much higher power density than the solid-state PV inverters installed only a few years earlier. Additionally, the IPC inverter occupied only 30 percent of the footprint of the previous solid state inverters, and 20 percent of the footprint of older metal core inverters.

The IPC inverters were priced at \$0.30/watt at the time, in line with other solid state inverter costs, and lower than older metal core inverter costs. More significant savings were realized in labor and materials for installation. Although no exact cost comparisons could be performed for the two inverter setups at NBVC, due to different vendors and periods of installation, it is clear that installation of a single unit would be quicker and less expensive than installing six inverters. Similarly, using larger metal core inverters would have required a fork lift and concrete pad, adding significantly to installation costs. Looking ahead, as more solid state inverters come to market, the price is trending downward.

### The Vehicle-to-Grid Charging Station

Under the same ESTEP project, a 60-kW Vehicle-to-Grid (V2G) DC fast charging station was installed at EXWC using two bi-direction battery power converters from IPC. This will enable multi-functionality from a universal hardware platform.

The demonstration not only validated the flexibility of a microprocessor software control approach to power converters, but also provided a new perspective on use of electric vehicles (EV) within the Department of Defense (DoD). The EV is primarily used as a transportation vehicle, but offers a portable electrical energy storage capability as well through its V2G port. The vehicle, manufactured by Phoenix Motor Car, was based on a Ford E450 chassis, converted to all-electric with a 4,000-pound load carrying capacity. The EV has been used extensively for short-run shipping and transportation of large components, and is available without the usual delays associated with



A V2G DC fast charger installed at NAVFAC EXWC in Port Hueneme, California.

scheduling a vehicle through base transportation. The vehicle also has a built-in inverter to provide AC power from its 100-kilowatt hour (kWh) lithium-ion battery modules, through 240- and 120-volt AC outlets. EXWC technicians have been able to load construction equipment onto the truck and perform repair and maintenance in the field without having to worry about the availability of power.

Additionally, the V2G capability of the vehicle can provide building backup power in case of power failure. This feature requires careful planning and an interconnect agreement with the local utility. V2G can also be used to provide ancillary power during peak demand hours—a practice known as peak shaving.

A rebate from the California Hybrid and Zero Emission Truck and Bus Voucher Incentive Program subsidized nearly 50 percent of the EV cost. This brought the

price of the EV to a level comparable to a gasoline-powered flatbed truck (with far superior functionality).

### Micro-grid

As DoD needs evolve beyond renewable generation toward energy resiliency, more attention is being paid to bi-directional power conversion, and management between load, generation and storage. After some of this functionality was demonstrated with the V2G vehicles, EXWC engineers turned their attention toward using such renewable generation assets on a building.

It comes as a surprise to many facilities owners that PV systems will fail to function when the grid is down. This is because the inverters that accompany a typical PV system serve only a single function—invert DC to AC power and send it onto the grid. When the grid is down, PV inverters

are designed to shut off because PV generation is intermittent and cannot provide stable power without a buffer such as the AC grid or an energy storage device.

EXWC is continuing with another ESTEP project to install and demonstrate the next phase in PV inverter development—a battery-integrated PV inverter. The 30 kW 3-port hybrid power converter chosen for this project, also manufactured

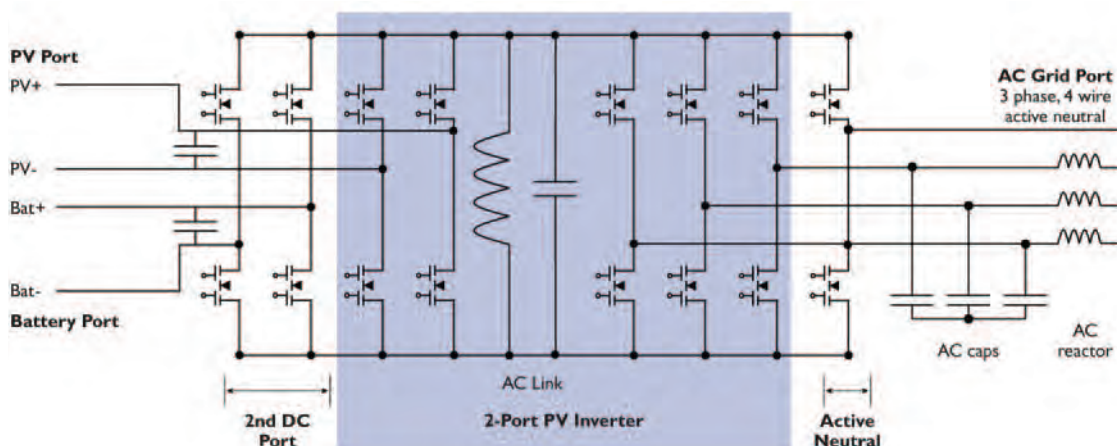
by IPC, was commercially available in 2015. Energy input from any of the unit's ports is stored within the device as "power packets" which can be converted and sent to any of the other two ports via microprocessor control. In this way, a building with installed PV can be converted into a simple building micro-grid. The building micro-grid is scheduled to be installed at an NBVC location in 2017.

Other ESTEP projects are looking at similar converters from this and other vendors.

### The Evolving Power Electronics Market

Multi-port inverters/converters are an important component of a resilient energy system. While multi-port inverter products have been around for quite a while, some of these products merely tie multiple converters together on a common bus and package them

EXWC technicians have been able to load construction equipment onto the truck and perform repair and maintenance in the field without having to worry about the availability of power.



The IPC 3-port hybrid power converter topology. The second DC port for the battery input is the same electrical architecture used for the DC port for the PV input. Energy input from any of the ports is stored in the AC link as power packets that gets converted and sent to any of the other two ports. Microprocessor control is critical in executing the complex switching needed to implement this topology.

*Ideal Power*

together in a single box with controls. These types of designs actually result in higher costs per watt and a very large footprint. As the need to integrate battery storage into PV systems grows, and newer multi-port inverters with smaller size and cost are introduced, there will likely be an increased demand for multi-port inverters.

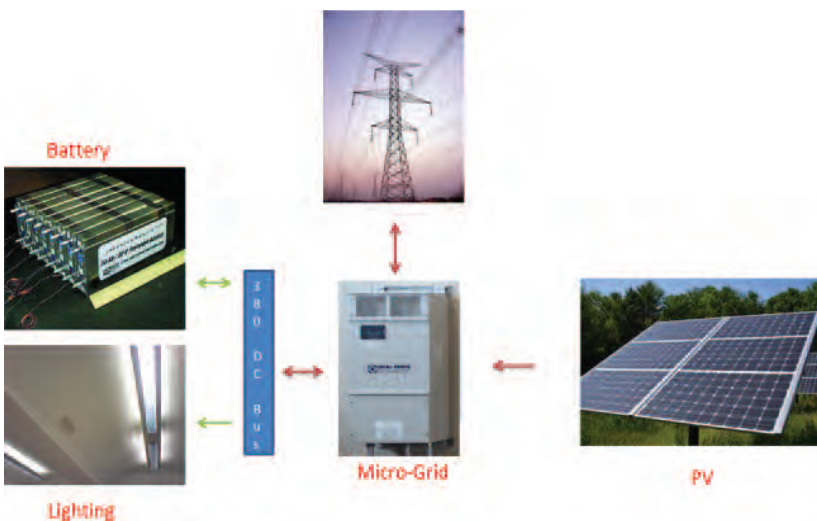
The IPC converters demonstrated as part of this project illustrate the general trend toward solid state power electronics with microprocessor control. The addition of microprocessor control has enabled unique topologies that were not feasible in the past. Since the start of this project in 2012, more companies have introduced solid state PV inverters with higher power density than PV inverters of five years past. EPC Power Corporation is one such company, harnessing microprocessor technology to produce a 500-kW inverter module small enough to carry under one arm.

As power electronics engineers become more familiar with designing power converters around

microprocessor control, newer products are sure to emerge.

Facilities managers should consider the cons as well as the pros of these new systems, however. The reliability of inverters based on solid state switching is inherently less robust than metal core transformer-based inverters, due to the larger number of components and the sensitivity of electronic components to environmental degradation. Reliability can be designed in, but proper design and

testing for reliability is more complex for solid state devices and needs to be done correctly to ensure reliability that will exceed 10 years. The market is trending toward smart solid state PV inverters and micro-grid converters. As more investment and time is put into development and manufacturing of solid state power devices, reliability will improve and can potentially match traditional metal core power devices. Already solid state PV inverters manufacturers are offering 10- to 15-year warranties.



Schematic of the building level micro-grid that is planned for an NBVC location.

Microprocessor control using software adds another parameter that has not been fully evaluated. These are a newer class of solid state power converters that is enabling multi-functionality and faster product development. Although these new advances in power electronics can provide flexibility in function, smaller size and lower cost, some facilities users may want to compare warranties or wait until reliability and robustness have been demonstrated over time before adopting them.

At the start of this ESTEP project in 2012, solid state PV inverters with large power capacity (over 30kW), were just beginning to replace larger


traditional metal core centralized PV inverters. Currently, the commercial-size centralized PV inverter/converter market is dominated by sales of solid state PV converters, validating part of this project's objective of reducing PV inverter costs by replacing metal core PV inverters with solid state devices. The next phase is to explore possible cost reduction in micro-grid systems with this new class of solid state power converters that use micro-processor controlled switching.

A universal power converter platform that can be achieved with programmable switching has the potential to reduce cost through faster product development and standard power

converter hardware. This new class of solid state power converters may not be ready for on-the-field reconfiguration to different applications, but its basic architecture will allow for quick product development and customization at the factory. With this new capability, systems integrators will have more flexibility in designing and implementing power management schemes. Rather than having to piecemeal various converters and selecting the proper power converter for each application, systems integrators can design around a universal platform. Much like car manufacturers using the same engine in various car models to reduce cost and expedite product development, a universal power converter platform can simplify development of power management schemes in micro-grids.

EXWC is exploring this next phase of study under continued ESTEP funding. A building level micro-grid employing these new programmable power converters is under construction

at NBVC Port Hueneme. EXWC is also helping installation energy managers at Marine Corps Air Station Miramar and Joint Base Pearl Harbor-Hickam to design and understand the benefits of these newer multi-port power converters in providing a

simpler, lower cost solution for integrating renewable energy into micro-grids. 

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## Read About ESTEP-sponsored Projects

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